JOL.20011112.0068

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Figure 1. Matrix and Effective Porosity at the Water Table of the SZ Site-Scale Flow and Transport Model. The area in which heterogeneous values of matrix porosity from the ISM rock properties model is outlined by the dashed line, as indicated. (Assumption 4 and DTN: SN0004T0501600.005)
Table 5: Coordinates of the Vertices of the Alluvial Uncertainty Zone.

<table>
<thead>
<tr>
<th>Vertex</th>
<th>UTM Easting (m)</th>
<th>UTM Northing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest (maximum westerly)</td>
<td>5552791</td>
<td>4066370</td>
</tr>
<tr>
<td>Northwest (minimum westerly)</td>
<td>5544152</td>
<td>4066020</td>
</tr>
<tr>
<td>Southwest (maximum westerly)</td>
<td>5488553</td>
<td>4057620</td>
</tr>
<tr>
<td>Southwest (minimum westerly)</td>
<td>548688</td>
<td>4057080</td>
</tr>
<tr>
<td>Northeast</td>
<td>557577</td>
<td>4066330</td>
</tr>
<tr>
<td>Southeast</td>
<td>555550</td>
<td>4066490</td>
</tr>
</tbody>
</table>

Figure 2: Alluvial Uncertainty Zone. The outline of the alluvial uncertainty zone is shown by the solid yellow line. Base map is a shaded relief map of surface elevation. The outline of the repository is shown by the solid blue line. Locations of wells with water-level measurements are indicated by the red crosses.
Figure 3  Radionuclide Source Regions for the SZ Site-Scale Flow and Transport Model. Source regions are outlined with the solid black rectangles and numbered from 1 to 4. The coordinates of the vertices of the source region rectangles are given in UTM coordinates (m). The outline of the repository is shown by the blue line (Source: Assumption 5). The dashed red lines indicate the quadrants from which radionuclide arrivals from the unsaturated zone model are applied to the SZ source regions. Coordinates of the dashed red lines are given in Nevada State Plane (NSP) coordinates (m).

6.2.3 Recharge from the UZ Site-Scale Flow Model

Within the area of the UZ site-scale flow model, the simulated groundwater flux at the bottom boundary of the UZ flow model (i.e., the water table) is applied as recharge to the upper boundary of the SZ site-scale flow and transport model. The values of recharge from the UZ site-scale model area used in the SZ site-scale flow model calibration are taken from a previous version of the UZ site-scale flow model (CRWMS M&O 2000c and CRWMS M&O 1999c, p. 6). For the analysis documented in this AMR, the values of recharge within the area of the UZ site-scale flow model are updated to utilize the most current UZ flow modeling results. Updating
Figure 6. Simulated Heads and Residuals at Wells from the Mean Flux Case of the SZ Site-Scale Flow Model (DTN SN0004T0601600.008). Contours show simulated head at the water table in units of meters above sea level. Head residuals at wells are shown in units of meters with the red labels. The repository outline is shown with the bold purple line in the upper central portion of the plot (Source: Assumption 8).
Figure 7. Simulated Heads and Residuals at Wells from the High Flux Case of the SZ Site-Scale Flow Model (DTN: SN0004T0501690.005). Contours show simulated head at the water table in units of meters above sea level. Head residuals at wells are shown in units of meters with the red labels. The repository outline is shown with the bold purple line in the upper central portion of the plot (Source: Assumption 5).

The probability of each of the three cases for a particular scaling factor can be determined from the cumulative distribution function (CDF) of uncertainty from the SZ expert elicitation. For a scaling factor of 10, the probability assigned to the low-flux case and the high-flux case is 0.24 and the probability assigned to the mean-flux case is 0.52 (CRWMS M&O 2000a).
Figure 8. Simulated Heads and Residuals at Wells from the Isotropic Case of the SZ Site-Scale Flow Model (DTN: SN0004T0591808-005). Contours show simulated head at the water table in units of meters above sea level. Head residuals at wells are shown in units of meters with the red labels. The repository outline is shown with the bold purple line in the upper central portion of the plot (Source: Assumption 5).
6.2.6 Implementation of Multiple Realizations

A series of radionuclide transport simulations are performed with the SZ site-scale flow and transport model for TSPA. A separate model run is conducted for each realization, for each radionuclide (or class of radionuclides), and for each of the four source regions. Parameter vectors for stochastic parameters are generated for all 100 realizations prior to the SZ site-scale model runs, using the parameter-sampling algorithm in the GoldSim software code. Results of the SZ site-scale flow and transport model runs are archived in files for use by the convolution integral subroutine of the TSPA simulator. UNIX script files are prepared to sequentially run the transport simulations and save the output files. A post-processor software routine is used to
Figure 10. Simulated Particle Paths in the SZ Site-Scale Flow and Transport Model (DTN SN0004T0601600 005). Simulated particle paths are shown in blue for isotropic conditions. The outline of the repository is shown with the bold red line (Source: Assumption 5). The 20 km fence is shown with the dashed red line. Locations of wells with water-level measurements are shown by the red cross symbols.
Figure 11. Simulated Unit Breakthrough Curves of Radionuclide Mass Flux for the Expected-Value Case. Results are shown for 20 km distance from source region 1 (DTN SN0054T0501600504).

Delay in the release of radionuclides afforded by the SZ is highly variable among the radionuclides that are simulated. Travel times through the SZ for $^{14}$C, $^{60}$Tc, and $^{125}$I are primarily less than 10,000 years, with many realizations having residence times of less than 1000 years. Sorption of $^{90}$Sr, $^{99}$Mo, and $^{103}$Ru in the alluvial units results in somewhat longer travel times for these radionuclides. $^{14}$C, $^{90}$Sr, $^{99}$Mo, and $^{125}$I are thus radionuclides of great concern for early releases from the repository and UZ, in the context of a 10,000 year regulatory standard. Travel times for Pu and Am subject to transport by irreversible attachment to colloids and U are near 10,000 years for the expected-value case as shown in Figure 11. $^{144}$Nd and radionuclides subject to reversible attachment to colloids have travel times in the range of about 20,000 years to 100,000 years in the SZ for the expected-value case, indicating that they are of lesser importance in the context of a 10,000 year regulatory standard.

Variability in the travel times through the SZ for a particular radionuclide among the realizations indicates a high degree of compound uncertainty in the transport processes in the SZ. Variations in the mean arrival times for different realizations apparently reflect the influences of sorption in the volcanic and alluvium units, the groundwater flux case, matrix diffusion in fractured units,
effective porosity in the alluvium units, and fraction of the flowpath in alluvium. Formal sensitivity analyses using the TSPA simulator will provide a quantitative assessment of the impact of individual parameters. The impacts of uncertainty in these processes, other than sorption, are visible in the breakthrough curves shown in Figure 12 for \(^{14}C\) transport in the SZ. Variations among realizations for sorbing radionuclides are even greater (e.g., see Figure 16).

![Simulated Unit Breakthrough Curves of Mass Flux for Carbon](image)

Figure 12: Simulated Unit Breakthrough Curves of Mass Flux for Carbon. Results are shown for 20 km distance from source region 1 (DTN: SN0004T0501600.004).
Figure 13: Simulated Unit Breakthrough Curves of Mass Flux for Iodine. Results are shown for 20 km distance from source region 1 (DTN: SN0004T0601600094).
Transport of really boring radionuclides. Results are shown for 20 km distance from source region. Figure 1. Simulated and experimental curve of mass flux for the TC model at Cordoba, Argentina.
Figure 15. Simulated Unit Breakthrough Curves of Mass Flux for the $K_0$ model for Colloid-Facilitated Transport of Moderately Sorbing Radionuclides. Results are shown for 20 km distance from source region 1. (DTN SN0004T0S01600.004)
Figure 16: Simulated Unit Breakthrough Curves of Mass Flux for Neptunium. Results are shown for 20 km distance from source region 1 (DTN: SN0004T0601600.004).
Figure 17. Simulated Unit Breakthrough Curves of Mass Flux for Colloid-Facilitated Transport of Irreversibly Attached Radionuclides. Results are shown for 20 km distance from source region 1 (DTN SN0004T0501600.004).
Figure 19. Simulated Unit Breakthrough Curves of Mass Flux for Technetium. Results are shown for 20 km distance from source region 1 [DTN: SN0004T0501800 004]
6.4 ABSTRACTION FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT

Two types of abstraction for TSPA analyses are discussed in this section. The convolution integral method is described with regard to incorporating results of the SZ site-scale flow and transport model in TSPA calculations. An abstracted method for including the effects of climate change is also described.

6.4.1 Convolution Integral Method

The convolution integral method is used in the TSPA-SR calculations to determine the radionuclide mass flux at the SZ / biosphere interface, 20 km downgradient of the repository as a function of the transient radionuclide mass flux at the water table beneath the repository. This computationally efficient method combines information about the unit response of the system, as simulated by the SZ site-scale flow and transport modeling, with the radionuclide source history.
Each pipe in the GoldSim model represents a one-dimensional mass transport model with uniform properties. The ratio of the volumetric outflow rate to the cross-sectional area of each pipe pathway represents the specific discharge in the pipe. A mass flux loading at the beginning of the first pipe is the source of the radionuclides that were transported along the connected pipes. The GoldSim model also provides a container that isolates all of the model components in one compartment to better organize the model components graphically on screen. For example, components of the one-dimensional mass transport in the saturated zone are contained in the container “SZ1D model” except for input, output, Species, Water, and MasterClock components (Figure 22). The “Species” component defines the radionuclides and their decay and ingrowth properties in the mass transport model. The “MasterClock” component controls the time and the simulation. Within the “SZ1D model” container, five pipes are used to represent the mass transport paths in the saturated zone (Figure 23). The “Pipe_5km” pipe is the transport pathway from the repository to a distance 5-km away from the repository boundary. The “Pipe_12km” pipe is the transport pathway from the 5-km distance to the boundary between the fractured volcanic hydrogeologic units and the alluvium unit. The “Pipe_20km” pipe is the transport pathway from the boundary between the volcanic units and the alluvium unit to the 20-km distance. The “Pipe_30km” pipe is the transport pathway from the 20-km distance to the 30-km distance. The “Pipe_80km” pipe is the transport pathway from the 30 km distance to the 80-km
distance. Hydraulic properties are generally grouped into two categories: fractured volcanic unit for the pipe pathways "Pipe_5km" and "Pipe_12km", and porous medium alluvium unit for the pipe pathways "Pipe_20km", "Pipe_30km", and "Pipe_80km". The input parameters correspond to those in the three-dimensional model and are generated by the parameter sampling module in the GoldSim software code. The sorption coefficients of $^{238}$U, $^{234}$U, $^{235}$U, $^{236}$U, and $^{237}$U are used directly (KDNPVO and KDUVO) in the matrix of the fractured volcanic units. There is no sorption within the fracture for the species. The sorption coefficients (KDNPAL and KDUAL) in the alluvium for the species are modified according to

\[ K_s^{*} = KDNPAL \cdot NVF19/0.35 \quad \text{or} \quad K_i^{*} = KDUAL \cdot NVF19/0.35 \]

where NVF19 is the effective porosity of the alluvium. This modification of the value of sorption coefficients is required in the effective porosity approach to maintain the appropriate retardation factor, as explained in the AMR on uncertainty distributions for stochastic parameters (CRWMS M&O 2000a).

Figure 22. One-Dimensional Mass Transport Model in the Saturated Zone.
Figure 23: Pipe Connection in the One-Dimensional Radionuclide Transport Model.

There is no matrix diffusion in fractured media for colloids with irreversibly attached radionuclides. Consequently, there is no sorption in the matrix for irreversible colloids. This is simulated by specifying an arbitrarily small value of available matrix porosity (\( \sim 10^{-6} \)) and zero sorption coefficients for these species in the volcanic matrix.

The retardation in fractures for colloids with irreversibly attached radionuclides is calculated according to the retardation factor (CORVO) of the colloids using the fracture coating option in the GoldSim software code. The equation for calculating the retardation factor in the fracture with the coating on fracture surface is:

\[
R_{\alpha,l} = 1 + \frac{P_T}{A_w n_c} (\rho \cdot K_{\alpha,l} + n_c) \quad (\text{Eq. 7})
\]

where \( R_{\alpha,l} \) is the retardation factor due to the coating, \( P \) is the perimeter of the pathway, \( T \) is the thickness of the coating, \( A_w \) is the cross-sectional area of the mobile zone, \( \rho \) is the dry bulk density of the coating material, and \( n_c \) is the porosity of the coating material. For a given value of \( R_{\alpha,l} \), the sorption coefficient is specified as:
and matrix diffusion coefficient $= 1.0 \times 10^{-15}$ m$^2$/sec. No dispersion is simulated in the verification. The breakthrough curves for time $t = 0$ to $3.0 \times 10^5$ days at distance $= 20000$ m calculated by the GoldSim and the analytical solution are shown in Figure 24. The two solutions match very well.

![Figure 24. Comparison of GoldSim and Sudicky and Frind (1982) Solutions.](image)

Simulation results with the SZ site-scale flow and transport model and the one-dimensional transport model are compared to check that implementation of the one-dimensional transport model is correct and consistent with the 3-D model. Results from the two simulation approaches are not expected to be identical because of dimensionality differences in the geometry of the models and variability in groundwater flux along the flowpaths in the three-dimensional SZ site-scale flow and transport model.

Figure 25 and Figure 26 show the breakthrough curves of carbon and neptunium at 5, 20, and 30 km for the expected value case of SZ flow and transport. The breakthrough curves are generally comparable, but not the same. For example, at 5 km, the breakthrough curves calculated from the one-dimensional radionuclide transport model show early breakthrough. One hundred realizations of the breakthrough curves for all of these seven radionuclides are also simulated. The results indicate that the breakthrough curves calculated by the one-dimensional radionuclide transport model show earlier breakthrough in some realizations and later breakthrough in other realizations. The difference may be caused by the uniform values of specific discharge and
material properties assigned from 0 to 5 km, from 5 to 20 km, and from 20 to 30 km in the one-dimensional radionuclide transport model. However, the average breakthrough times are generally comparable for the one-dimensional radionuclide transport model and the three-dimensional SZ site-scale model.

Figure 25. Simulated Breakthrough Curves From the One-Dimensional Transport Model and the Three-Dimensional SZ Site-Scale Model at 5, 20, and 30 km for Carbon.
Figure 26. Simulated Breakthrough Curves From the One-Dimensional Transport Model and the Three-Dimensional SZ Site-Scale-Model at 5, 20, and 30 km for Neptunium.